Fundamentals of Interference in Mobile Networks

COMPUTING
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Recognizing the Sources and Consequences of Interference in Wireless RF Signals

What Is Interference?

You are investigating reports of dropped calls, noisy connections, lost channels and poor reception in one of your base station coverage areas. The equipment at the station checks out, but something is still corrupting the communication channels. There is a long list of possible offenders capable of creating signals that accidentally or intentionally interfere with wireless RF signals. This application note will help you better understand interference sources and identify them using new measurement tools and techniques.[1]

The potential for interference is growing at an alarming rate. Sophisticated new telecommunications technology must coexist in a complicated landscape of previous generations of mobile systems like specialized mobile radio and paging – most of which will continue to operate for many years to come. Other wireless RF devices such as digital video broadcasts, and local networks are introducing new signal sources that threaten to disrupt service. Cell towers are bristling with antennas of all sorts, driven by growing environmental restrictions, competition among many new services and a limited number of suitable cell sites. The communications sky will become even more crowded, as more of us talk to each other on mobile phones, watch multimedia shows and trade stocks on the Internet – soon, even our cars, refrigerators, and toasters will be trying to communicate with each other.

Where Does Interference Come From?

Most interference is unintentional – the byproduct of another legitimate activity. Here are a few of the most common sources to give you some ideas of what to look for in a field situation. Notice that most of the sources are external to the base station and beyond your direct control.

[1]For additional information, see *Hunting for Sources of Interference in Mobile Networks,* a companion application note from Tektronix.

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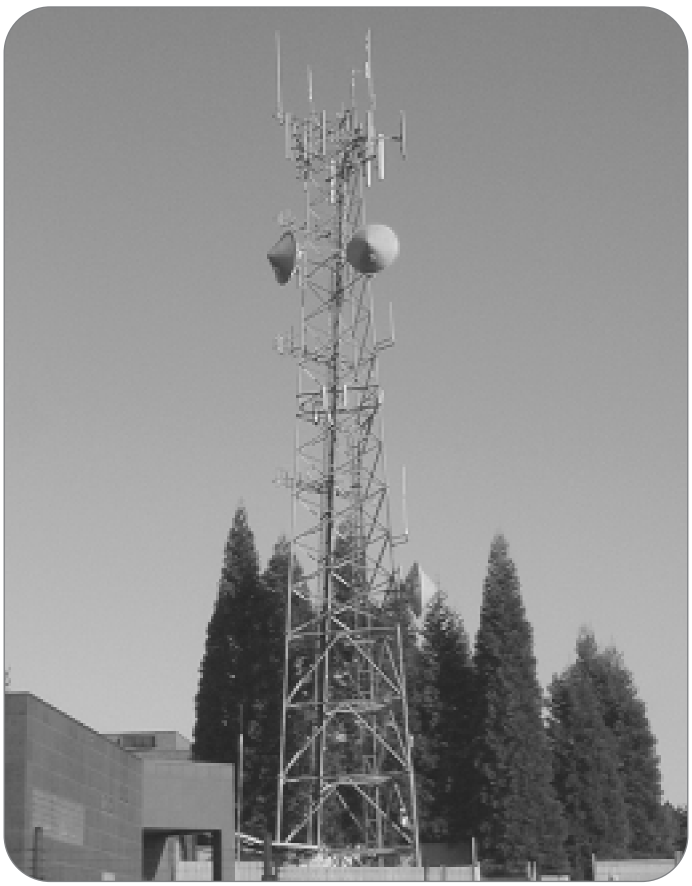
Improperly Configured Transmitter

Another operator is transmitting on your frequency. Most often this is the result of a fault or an incorrect setting; and the operator of the transmitter would be happy to correct it to restore his own service level.

Unauthorized Transmitter

In this case, the operator is intentionally operating in the same frequency band – usually because he has no license at all. He probably started his operation when he found no transmissions in the band and assumed that nobody was using it. The governmental agency that issues licenses is usually helpful in getting rid of these interlopers.



▶ ***Figure 1:*** *Sign of the times: Here is a site with nearly thirty separate communications antennas mounted on the same tower as the cellular and PCS systems. With this many signals present in a small space, there is a much greater chance of them interfering with one another.*

Cell Overlap

A cell from your own network, or others, exceeds specified coverage in one or more channels. Incorrect antenna tilt, excess transmitter power, or a change in the environment can cause overlap (for example, someone may have cut down a forest of trees that had been blocking the signal from that site.)

Intermodulation from Another Transmitter (see sidebar)

Intermodulation interference can be the result of one or more external radio signals getting into the antenna feeder coax and entering the offending transmitter's non-linear final amplifier stage. The external signals mix with each other and with the transmitter's own signal, creating intermodulation products that appear as "new" (and often very undesirable) frequency components in the communications band.

It is also possible for two other external signals to produce an interfering signal when neither one is from the offending transmitter, they just use its non-linear stage to mix together. In this case neither of the two signals that are mixing together is at fault – the transmitter is the culprit.

The solution to this problem is a bit difficult, since it may require changes to a transmitter that appears to be functioning properly. A narrowband filter can be added to attenuate the outside signals as much as possible along with a ferrite isolator that lets RF pass from the transmitter to the antenna and attenuates signals coming back from the feeder. Tower owners at shared sites where many different frequencies are in use often require the installation of such filters and isolators in all transmitters.

Intermodulation in a Rusty Fence, Roof, Etc.

Transmitters are not the only breeding ground for intermodulation products – the non-linear junction could be a nearby rusty tin roof or fence. In the presence of high-power radio transmissions, the rust between the individual roof sections can act as a non-linear diode. The intermodulation effects from physical structures such as these are difficult to pin down, since they vary with weather conditions – as wind presses parts of the rusty metal together and apart and rain alters the characteristics of the rust. Seriously offending structures must be repaired or replaced in order to restore reliable communications.

Intermodulation in Antennas or Connectors

Sometimes, even minor corrosion in a coaxial connector or the antenna itself will create a problem. While not enough to cause signal loss or a VSWR problem, the corrosion can act like a very poor diode and cause just a little bit of intermodulation. In an environment of several nearby high-power transmitters, the resultant intermodulation can be strong enough to interfere with the weaker signals from mobiles trying to communicate with the base. The most difficult part of finding this culprit is the fact that if you loosen a connector in the antenna system to see if the problem is at that point, you disturb the oxide and stop the problem. It may not come back for several months. In this situation you may want to use extra time to carefully note which connectors you are re-loosening or re-tightening and test for a while after each. Then if the problem goes away after touching a particular connection, it might be the one. Only time will tell.

Overload From a Legitimate Transmitter

Occasionally, strong signals from a transmitter at any frequency can overload a neighboring system. The only solution is to install a filter on the receiver antenna cable that will pass the intended signals and attenuate the overload signal.

Adjacent Channel Power from a Neighboring Transmitter

As the allocated spectrum becomes more crowded, competing radio services are being given frequencies closer together – increasing the risk of noise sidebands from the transmitting channel of one system appearing in or blocking the adjacent receiving channel of another. If the transmitter is meeting required specifications, you may need to change channels or increase the separation between the transmitter and receiver.

Harmonics from Broadcast Transmitters

High-powered sources, such as commercial broadcast stations, can produce substantial energy in harmonics of their signals. For example, a 5-megawatt transmitter can easily generate 5 watts of harmonics – more than enough to interfere with nearby mobile communications. If the transmitter in question meets all of its specifications and government regulations, the only practical solutions may be to move the communications antenna to shield it or to re-allocate the frequency plan so that the cell sites near the offending transmitter use channels not affected by the harmonic energy.

Intermodulation

When two or more RF signals meet in a non-linear device, they mix together creating Intermodulation (IM) products from the sums and differences of their harmonic frequencies. The generalized formula for two signals is: (X • A) + (Y • B) and (X • A) - (Y • B), where A and B are the two mixing radio signals, and X and Y are the harmonic numbers of the signals. The harmonics may range from 1 (the fundamental) to any higher integer number. In practice, harmonics above the 10^{th} or 15^{th} rarely produce enough power to impact other sources.

The simplest form is "Second Order" IM, which produces the sum and difference frequencies of two fundamental signals: A + B and A - B. Signals of 879.900 MHz and 857.400MHz will produce second order products at 1737.300 MHz and 22.500 MHz.

The more common occurrence is "Third Order" IM – the first harmonic of one signal mixing with the second of another, or three fundamentals mixing together. The simplest form is 2A + B and 2B + A for summation products and 2A - B and 2B - A for difference products.

For example, a cellular site with US TDMA operating on channel 330 downlink at 879.900 MHz has an associated uplink frequency of 834.900 MHz. A nearby SMR (Specialized Mobile Radio) site could be operating a downlink on their channel 256 at 857.400 MHz. Summation third order products are far too high to cause problems to the site; (2 • 879.900) + 857.400 is clear up at 2617.200 MHz.

The upper difference mix product is also not a problem for this site; (2 • 879.900) - 857.400 = 902.400 MHz. However, the lower difference product, (2 • 857.400) - 879.900 = 834.900 MHz – exactly the same as the TDMA uplink frequency. This product could completely block signals from the mobiles trying to reach the site.

The formula for three fundamental frequencies computes all cases of plus or minus signs for all of the frequencies, yielding eight possible combinations of the original frequencies. In most practical cases, the three frequencies are near each other and the most common IM products produced are at: A + B - C, A + C - B, and B + C - A.

Calculating all of the possible IM products for a given radio site can be a daunting task. A site with 30 radio channels in use will produce about 14,350 possibilities of the most common third order mixes alone! Fortunately, we have computer programs that can help us with this task.

"Grandfathered" STL Users

Before the advent of cellular systems, the 900 MHz and 1400 to 2200 MHz bands were often assigned to studio-to-transmitter links (STL) for broadcast stations. Governments have largely re-assigned these frequencies to cellular operators, but frequently "grandfathered" the old users, allowing them to continue operations. Those transmitters were supposed to move frequencies when new cellular operations are established, but some may need a "reminder."

Audio Rectification

In rare cases, where the base station's controller side still uses analog audio input to the radio, the site can be affected by a strong signal from a nearby AM broadcast or short-wave station. It is possible for the AM signal to get into the audio circuitry and be rectified, adding the broadcast audio in with the phone conversation. Better shielding around the audio connections to the base radio should solve this problem.

Recognizing Types of Interference Sources

Interference can be categorized by its own characteristics, as well as by its effect on the desired communications. It can be found at the Base Station and in the air interfaces with the mobiles. Interference signals only affect receivers – even when they are physically close to a transmitter, the transmission will not be affected. The frequency of the offender is the most common indicator of the source and consequences of the interference.

Off-Frequency Sources

A major class of interference includes strong signals that are not at the exact receiver frequency, but are strong enough to affect its input. These signals are usually very close to the intended frequency, since the receiver's input filter should eliminate the rest.

Look for one of two effects in the receiver. Front end blocking is caused by a strong signal entering the receiver and overloading the first stage (either a preamplifier or a mixer) to complete saturation. This type of interference usually prevents even fairly strong signals from being received. The other effect is desensitization. A nearby signal gets into a receiver and is detected by the AGC, or activates the limiter circuitry, reducing the gain. The receiver acts as if it were simply less sensitive – weaker signals will be lost and the signal-to-noise ratio will be degraded for stronger ones.

On-Frequency Sources

The second class of interference includes signals (weak or strong) that are at the same frequency as the intended communications signals. These are most commonly caused by:

- Legitimate cellular signals that are extending beyond their intended range.
- Malfunctioning or misconfigured transmitters
- Other electrical devices that emit unintended interference.
- Harmonics of legitimate transmitter signals.

Off-Frequency Sources that Produce On-Frequency Effects

The most difficult to track down, this class of interference appears to be a signal that is on your frequency with no apparent source. The signals that create it are at substantially different frequencies, but are being combined into a new signal at your frequency. An example of this type is an intermodulation product created from two or more signals that are properly at their own frequencies, but are mixing in a non-linear element.

Intentional Interference

Intentional malicious interference is usually on-frequency, acting a lot like a misconfigured transmitter. We give it its own class because it often has especially elusive and pernicious characteristics.

An extreme example of this class was one that attacked a two-way radio repeater system in a remote forested mountain location. The system began to receive a very weak signal on its input frequency (including the correct tone coding to activate the repeater), but only during the hours of darkness. The signal stayed on the air constantly, which tripped the repeater's timeout relay and disabled the system until morning, when the signal disappeared. It was particularly difficult to locate the source because the signal was too weak to be detected at ground level and it was only transmitting at night. When it was eventually located, the interference source was found to be a miniature transmitter with a small solar panel that had been placed in a treetop near the repeater antenna mast. The transmitter had been shutting down during the day while its solar panel recharged the batteries.

Harmonics

The preceding classes describe clean original signals. In real-world situations the signals may contain harmonics of the fundamental frequency that are strong enough to cause interference. For example, a UHF TV transmitter in the U.S. is required to have a filter to reduce its harmonics to at least 60 dB below the main carrier. The most troublesome harmonic is usually the third, since it can easily be generated by very small non-linearities in the transmitter. A 5 Megawatt TV transmitter operating on 621.25 MHz, has its third harmonic at 1863.75 MHz. Even at 60 dB down (after filtering) the third harmonic would still produce 5 Watts! A signal at this frequency and power level radiating from a high point overlooking a city could easily wreak havoc on cellular signals throughout the city.

Harmonic signals have another characteristic that makes it more difficult to identify their source. The multiplication process that creates the harmonic alters the spectrum signature as well – its width and deviation are multiplied by the same factor as the carrier frequency. A 13 kHz wide 2-way radio FM signal at 157.54 MHz would have a 10^{th} harmonic that is 130 kHz wide. In addition, a 5 kHz deviation of the fundamental would become 50 kHz at the harmonic frequency of 1575.4 MHz. If such a transmitter were sharing a tower with a base station, the harmonic could completely cover up the GPS receiver – disabling the station. For a 100 Watt FM transmitter, a total of about 195 dB of attenuation would be required to avoid interference, which could be achieved with a combination of antenna isolation and filter suppression.

Table 1 lists some of the signals whose harmonics could generate enough power to cause widespread interference. There are many more that could provide localized interference.

Table 1. Some Examples of Harmonic Interference Sources

Cellular Band	Frequencies (MHz)	Interference Source	Harmonic number
US Cellular Base Tx	869 – 894	VHF TV ch 7 (US)	5
GSM Base Tx	925 – 960	VHF TV ch 6,7 (Euro)	5
		UHF TV ch 21,22 (Euro)	2
GSM Base Rx	880 – 915	VHF TV ch 5,6 (Euro)	5
US PCS Base Tx	1930 – 1990	UHF TV ch 42 to 46 (US)	3
		UHF TV ch 16 to 18 (US)	4
		Land Mobile 480 MHz	4
US PCS Base Rx	1850 – 1910	UHF TV ch 38 to 41 (US)	3
		UHF TV ch 14 to 15 (US)	4
		Paging 930 MHz	2
GSM 1800 Base Tx	1805 – 1880	UHF TV ch 37 to 40 (Euro)	3
GSM 1800 Base Rx	1710 – 1785	UHF TV ch 33 to 36 (Euro)	3
IMT2000-FDD Base Tx	2110 – 2170	UHF TV ch 28 to 29 (Euro)	4
		UHF TV ch 50 to 52 (Euro)	3
IMT2000-FDD Base Rx	1920 – 1980	UHF TV ch 22 to 23 (Euro)	4
		UHF TV ch 42 to 44 (Euro)	3
GPS receiver	1574.9 to 1575.9	UHF TV ch 23 (US)	3
		UHF TV ch 66 (US)	2
		UHF TV ch 27 (UK)	3
		UHF TV ch 60 (Euro)	2
		Paging 157.54 MHz	10

Intermodulation

Intermodulation has unexpected characteristics. Several signals may be mixed and create new modulation products that do not necessarily follow any of the expected types. The most common intermodulation products are third order. Two signals separated by 1 MHz would produce one new product located 1 MHz above the higher of the original two, and the second new one 1 MHz below the lower (originals of 800 and 801 MHz would have third order products at 799 and 812 MHz).

When measuring intermodulation interference, be sure that the measuring instrument is not contributing its own distortion. Any spectrum analyzer or other RF measuring tool has its own dynamic range or "third order intercept." If the measuring tool is causing intermodulation, it will be unable to tell which it is seeing – incoming products or its own products. The solution for this problem is to use an external filter that passes only the intermodulation product that you are looking for and rejects the strong signals that made it.

Conclusion

There is a long list of possible offenders capable of creating signals that interfere with the wireless RF signals and plague cellular communications systems. This application note has described interference sources and the places within communications systems where the interference causes problems. Interactions between multiple offenders has also been discussed.

A companion application note from Tektronix, "Hunting for Sources of Interference in Mobile Networks" will help you better recognize those interference sources and gather "evidence" to prove your findings. It will also explain in detail the operation of the latest Tektronix innovations that simplify and speed your search.

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